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COMPUTER-AIDED PROCEDURE FOR COUNTING WATERFOWL ON AERIAL PHOTOGRAPHS

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Birds that aggregate for breeding or during migration are often censused visually by observers on the ground or in low-flying aircraft (e.g., Kadlec and Drury 1968, Piatt and McLagan 1987). The accuracy of visual counts depends largely on viewing conditions and observer experience (Caughley 1974, Erwin 1982). Furthermore, accuracy diminishes rapidly as the number and density of birds to be counted increases (Arbib 1972, Samuel and Pollock 1981).

Aerial photographs can be used to precisely record and later quantify large aggregations of birds, and to estimate the error associated with visual counts in the field (Heyland 1972, Leonard and Fish 1974). However, visual counts of bird images on photographs can also vary between observers and with counting technique. With hundreds or thousands of bird images on a single photograph, counts by different observers may vary up to 100%, and those repeated by a single observer may vary up to 40% (Harris and Lloyd 1977, Erwin 1982, Gilmer et al. 1988).

More precise counts can be obtained if photographs are digitized and bird images are quantified on the basis of photographic density (Bajzak 1974). For example, Gilmer et al. (1988) digitized photographs of snow geese (*Chen caerulescens*) and Ross' geese (*C. rossii*), and with the aid of a computer, measured the area of photographs with optical densities above a threshold value representative of white phase snow geese. That area was divided by the average area of a single goose to estimate the total number of geese on the photograph. Results of this technique may vary if background habitats contain density values corresponding to those of the images being quantified, and will depend on the size distribution and spatial orientation of birds on the photograph. In the study of Gilmer et al. (1988), computer counts differed by up to 15% from observer counts.

We present a more refined technique for computer-aided counting of greater snow geese (*C. caerulescens atlantica*) from digitized photographs using a computational algorithm for the identification of individual birds. Besides obtaining a precise count of bird images, our method can be used to sort counted birds into size and tonal (photographic density) classes. This technique has potential for use in counting different species and sex or age classes of birds in mixed waterfowl assemblages. The described method was developed through analysis of many digitized aerial photographs of snow geese, common eider ducks (*Somateria mollissima*), canvasbacks (*Aythya valisineria*), redheads (*Aythya americana*), and American black ducks (*Anas rubripes*) (Bajzak 1972, unpubl. rep.). These investigations indicated that the best result could be obtained if individual birds were recognized separately in the digital field and that the computer counting technique using image tone alone is best suited to uniformly colored species.

METHODS

We chose the greater snow goose for study because the species is well suited for aerial photographic censusing. The white plumage contrasts sharply with many of the habitats used by snow geese. During spring and fall migration, the entire population stages over 6 to 8 weeks on tidal flats of the St. Lawrence River, Quebec. Flocks containing up to 140,000 birds are not unusual in this setting (Heyland 1972).

Photographs were taken during several experimental and operational flights in the St. Lawrence River area. We used panchromatic, natural color, and color infrared films for the experimental photography. The picture that we analyzed in this study was taken with a Zeiss RMK 60-23 camera, having a focal length of 610.97 mm, from an approximate altitude of 1,400 m. A contact positive transparency made from the original Kodak panchromatic aerial film was digitized. A SCANDIG Type 1 scanning micro-densitometer connected to a Kennedy tape deck was used to digitize the photographic film. This is an "off-line" scanner with computer-compatible tape output similar to the instrument described by Lillesand and Kiefer (1987). On our instrument, 50-, 100-, and 200-micrometer scanning apertures were available. Selection of aperture size depends on the minimum dimension of the object to be counted. To distinguish individual objects with the computer using our method, we needed at least 4 points per image. We selected the 100-micrometer aperture because it provided 5 to 55 image points per goose. Use of 50- or 200-micrometer apertures would have been inappropriate as they would have resulted in too many or too few points per goose image. The micro-densitometer scanned along the Y and X axis of the photographic transparency. The output, recorded on magnetic tape, provided a relative photographic density value (emulsion darkness beneath the scanning aperture) for each of the image points in an XY matrix of the digitized picture. The instrument can measure relative photographic densities ranging from 0 to 255 representing 100% to 0% transmittances of the film, respectively.

The digital XY matrix was analyzed by the computer using 2 FORTRAN programs. The first program produced a printed output of density values from a specified data matrix (e.g., a selected subset of the scanned photographic transparency). This output was used to determine the required parameters for computer identification and counting of images. We required parameters representing the tonal range of snow geese and the minimum and maximum number of points within a bird. The second program identified individual birds based on criteria from the first analysis, counted the number of points per bird, and calculated the minimum, maximum, and average densities for each of the identified birds. The program also tabulated the total number of birds found within a specified area of the digitized field. This program was written to classify counted birds into a maximum of 5 different classes based on size, tone density, or both.

We recognized that the initial choice of parameters might not result in an accurate computer count of birds. To test the accuracy of the initial counting procedure and to make the necessary changes in parameter values for a final count, a small subset of the matrix (training area) was counted by the computer before attempting a total count for the entire digitized transparency. Based on the results of this test, the tonal densities and the number of points representing a goose were adjusted so that computer counts and test counts agreed.

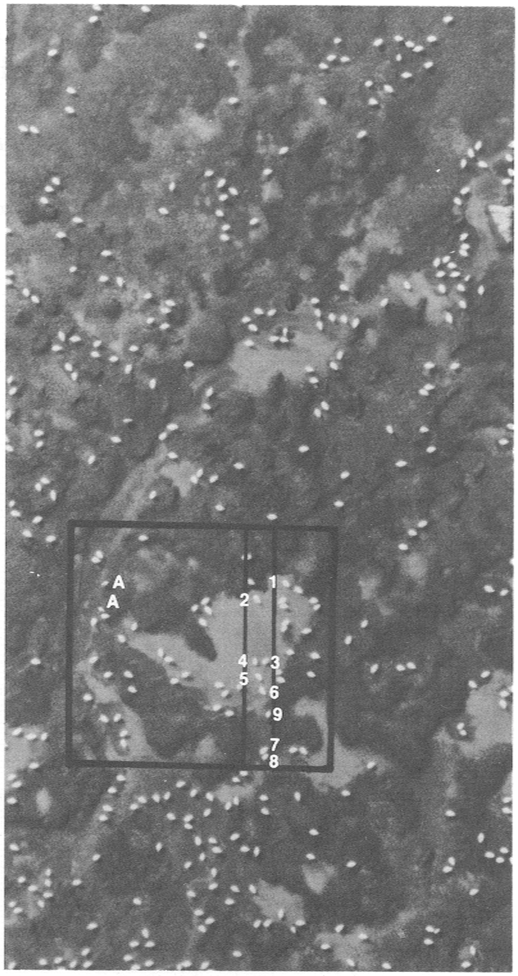

Fig. 1. Aerial photograph of greater snow geese (white dots) feeding on mud flats of the St. Lawrence River near Quebec City. The delineated rectangle encompasses the training area used to establish parameters for computer-aided bird counts. Numbered goose images correspond to those in Table 1, whereas bird images marked (A) are not snow geese.

RESULTS

We analyzed a section of a 23- × 23-cm contact positive print. The digitized image contained a matrix of 2,880,000 (1,800 by 1,600) points. The delineated portion of this aerial photograph (Fig. 1) was used to establish parameters for the counting procedure and to

109	109	107	105	103	104	104	105	105	105	103	100	101	103	103	104
110	107	105	104	103	104	103	102	103	101	99	96	97	101	102	103
110	108	106	104	104	103	101	99	99	98	95	92	93	94	95	99
109	108	105	103	102	101	97	93	94	91	86	85	83	83	85	91
107	105	103	103	100	95	90	86	83	79	71	71	70	71	77	85
107	103	103	101	97	89	79	75	71	63	61	59	60	66	74	85
105	105	101	98	89	79	71	63	57	54	53	55	60	68	80	88
106	103	99	91	82	71	61	55	52	50	51	56	64	73	85	93
107	103	99	88	77	65	55	51	50	51	53	58	68	79	90	96
104	103	98	88	75	62	55	51	51	52	56	64	74	84	96	101
108	104	98	87	75	62	56	54	53	56	61	70	81	91	100	105
108	105	100	88	75	65	58	56	57	60	69	78	88	94	102	108
108	105	100	89	76	68	66	65	66	70	77	85	90	93	98	101
109	106	100	89	80	76	76	76	76	78	81	83	83	83	85	89
109	105	100	94	90	88	88	86	83	81	77	73	71	71	71	79
110	106	102	100	99	98	96	89	83	74	63	61	59	61	66	77
111	107	102	103	104	101	95	85	74	63	57	53	55	59	66	79
110	107	104	104	103	99	90	77	66	57	53	52	55	59	69	82
110	107	107	107	103	98	86	74	62	56	54	55	59	65	76	90
109	109	109	107	104	99	88	76	64	57	56	57	62	72	83	97
109	107	107	107	104	101	92	80	70	61	60	64	70	80	92	104
107	106	107	107	105	103	99	88	78	70	69	72	80	89	100	109
107	106	107	107	106	105	102	96	88	82	82	85	96	101	108	112
106	105	105	106	105	106	105	101	96	96	96	98	104	108	112	115
105	103	104	103	105	107	106	103	101	100	101	104	109	111	113	116

Fig. 2. Digital image of greater snow geese No. 7 and No. 8 from Fig. 1 illustrating range in tonal values and number of pixels needed to distinguish geese (delineated by lines).

Table 1. Sample output (no. of image points and average photographic density value) of the delineated strip shown in the aerial photograph (Fig. 1) of snow geese on mud flats of the St. Lawrence River, Quebec, October 1969.

Bird no.	No. of points	Average density	
		$\bar{x}$	SD
1	16	56.9	1.81
2	44	52.1	3.80
3	22	55.2	2.33
4	5	58.4	0.55
5	24	56.4	2.11
6	31	54.1	3.23
7	28	54.1	2.63
8	17	56.1	2.25

verify the initial computer count of snow geese. The digital output for this area was examined, and point values representing individual birds were determined. Visual inspection indicated that relative density values of a snow goose image were approximately between 40 and 55, and that an individual goose image was made up of 5 to 35 points. For example, the digital images of the snow geese numbered 7 and 8 (Fig. 1) clearly contrast with their background (Fig. 2).

Our test of the training area indicated some geese were not counted. For example, the image of bird No. 2 had >35 image points. Other birds were ignored because their image point densities were outside of the specified threshold of 40 to 55. As a result, the values of counting parameters were changed: the maximum darkness value was increased to 59, and the maximum number of points representing a bird image was increased to 50. Using these new parameters, birds in the training area were recounted by computer. Output from the program (Table 1) can be compared directly with the actual photograph as the bird identification numbers correspond to those on the photo. The total number of birds counted in the delineated strip shown on Fig. 1 was 8 with an average density of 54.6 and 23 points per bird image. Goose No. 9 was not counted because its image was made up of values greater than the specified threshold (darker image). In addition, 2 other birds within the entire training area (A in Fig. 1) were not counted because their images were lighter than the defined tonal range. However, these 2 birds were other waterfowl species, not snow geese.

The computer count using the new parameters for the entire training area was 54, whereas the visual count was 55. We considered this acceptable, and a final computer count for the entire aerial photograph estimated 695 snow geese to be present. To test the accuracy of the final count, 6 different observers visually counted the number of geese on the photograph. The mean of these visual counts was 711 (SE = 1.4) birds. This represents only a 2.3% difference between visual and computer counts. The computer count was less than the visual count because some birds were darker than the majority of the population. This darkness difference was not detected by the human eye, but was measured by the densitometer.

Eight minutes of scan time were required to digitize the photo we used. The preliminary data analysis and the establishment of relevant parameters for the count took approximately 1 hour. The computer CPU time was minimal. However, our experience indicated that if >1 photograph in a roll of film is digitized, parameter values for each individual frame should be validated separately because exposure and processing differences can exist between consecutively exposed photos.

DISCUSSION

Aerial photography, combined with computer-aided counting, offers great potential for censusing animals that at times aggregate in relatively small areas. Photographic images can be quantified by counting the total number of image points falling within an established threshold limit and dividing that total by the average number of points representing one bird image (Gilmer et al. 1988), or individual birds can be identified and counted separately by searching for clusters of points that meet a predefined size and photographic density range. We believe the first technique is more susceptible to bias because the number of image points composing a single target animal can vary greatly. For example, in our study, between 5 and 44 points ($\bar{x}$ = 23) represented a goose in a sample of 8 birds (Fig. 1, Table 1). For 54 birds counted in the training area, the average was 28, and for 695 birds in the entire photograph it was 33. The variation of image points per bird was mainly due to the orientation of birds at the instant of photography (i.e., the image size of a bird differs if feeding, standing upright, or sitting). In addition, individual geese vary in size. Image points of other objects having the same values as geese will be included in the count of the averaging technique. However, we control this problem in our procedure by establishing a limit (minimum and maximum) on the number of adjacent points that can form one goose image. To increase the accuracy of the count, shape analysis could also be applied to the individual digital bird images.

Our technique can also sort the counted birds into size and/or darkness classes. Sorting had no practical application in the present study because each snow goose had similar white plumage, and there were no size differences between birds that could be associated with particular snow goose characteristics (e.g., age classes). However, sorting could be used to classify and count birds in mixed species groups. When combined with appropriate shape algorithm and texture analysis, it could be used to distinguish and count sexually dimorphic species.

SUMMARY

Although sophisticated statistical procedures are often used to design animal censuses, errors inevitably arise from visual counts during field surveys. This is especially true for low-altitude aerial censuses of large, aggregated populations. Aerial photographs can provide precise, permanent records of animal numbers observed during surveys, but precision can be lost when photographic images are later enumerated by human observers. We describe a computer-aided counting technique applied to digitized aerial photographs of greater snow geese (*Chen caerulescens atlantica*). A similar technique was found to be more efficient than visual counts of photographic images if the number of birds exceeds 2,000 per photo (Gilmer et al. 1988). However, that technique involves elaborate photographic processing and uses photographic image density alone to quantify bird numbers. We believe our procedure is more accurate because it does not rely only on average density values, but also recognizes individual birds by defining the size of images to be counted. This technique might be improved further by introducing shape and texture analysis, thus allowing its use for the census of mixed species assemblages. We are presently working on this problem, and will release our computer programs for public use after we complete this phase of the work.

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